Static Environmental Testing of a Cocured Aircraft Wing Test Box

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ABSTRACT

Existing primary aircraft structures are typically fabricated by fastening the skins to the internal substructure. However, there are several advantages for opting for a cocured route of fabrication wherein, instead of fastening, the skin and the substructure are cured together. Keeping in view the advantages, an attempt has been made at NAL to develop the fabrication technology for a cocured wing test box that is of the same scale and designed for the same loads as the rear root fitting box of a combat aircraft. After completing the static tests for the ultimate load, the box was placed in an environmental chamber for more than a year and exposed to temperature and moisture. The conditioning of the test box was done along with different specimens and features, which apart from indirectly indicating the moisture content in the box, also provided some interesting insights into the mechanism of moisture absorption. After ensuring saturation of moisture, the hot-wet testing of the box was carried out. The tests were done with the box enclosed in a special in-situ environmental chamber. The comparison between the results for the room temperature test results and the hot-wet test results are presented here and discussed. The results indicate that it is feasible to design and fabricate wing structures using co-curing technology.

Keywords: composites, cocuring technology, wing test box, environmental testing

1. INTRODUCTION

Existing primary aircraft structures, specially the wing, are typically fabricated by fastening the skins to the internal substructure comprising spars and ribs. This type of construction increases (i) the production time and costs due to the need for assembly, (ii) the weight because of the fasteners, and (iii) maintenance issues, especially in a wet wing where fuel leakage at the fastener locations is not uncommon. Moreover, fasteners gives rise to stress concentration areas leading to fatigue and other related structural integrity and maintenance issues. One way of overcoming the above problems is by using composite materials to fabricate the structure wherein the the skin can be cocured with the substructure. Additionally, a bonded construction results in a stiffer structure as compared to a bolted construction leading to reduced dynamic and aeroelastic problems. Clearly, there are advantages for opting for a cocured route of fabrication. Indeed, for the reasons listed this technology has been applied for many aircraft parts. However, this has been until now restricted to empennage, control surfaces, fuselage parts, etc due to relatively lesser complexity as compared to the wing. Keeping in view the advantages mentioned above, an attempt has been made at NAL to develop the fabrication technology for a cocured wing. Towards this end a test box that is of the same scale and designed for the same loads as the rear root-fitting box of a combat aircraft was fabricated using the co-curing technology.

The wing test box is designed for static loads in room temperature (RT) and hot-wet (HT) conditions. The design is also aimed at finalising the structural details such as the T-joint configuration (the skin-stiffener joint), the rib-spar junctions, etc. The geometry of the test box is shown in Figure 1. The test box is about 1.6 m in length, 1.2 m in width and 236 mm in height. The top and bottom skins are flat and parallel to each other, both in the chordwise and spanwise directions. The structure consists of metallic and CFC (carbon fibre composite) components. The CFC components are the Spars, Ribs, and Skins. The thickness of the skins varies from around 16mm to 6mm. The metallic components include the root fittings, shear bracket, part of the auxiliary root rib (mid portion), and the fasteners. Spars 11 (11A and 11B), 12 (12A and 12B) and 13 (13A and 13B) and the Pylon Rib are co-cured with the bottom skin as shown in Fig 2. A view of the partially assembled box is shown in Fig. 3.

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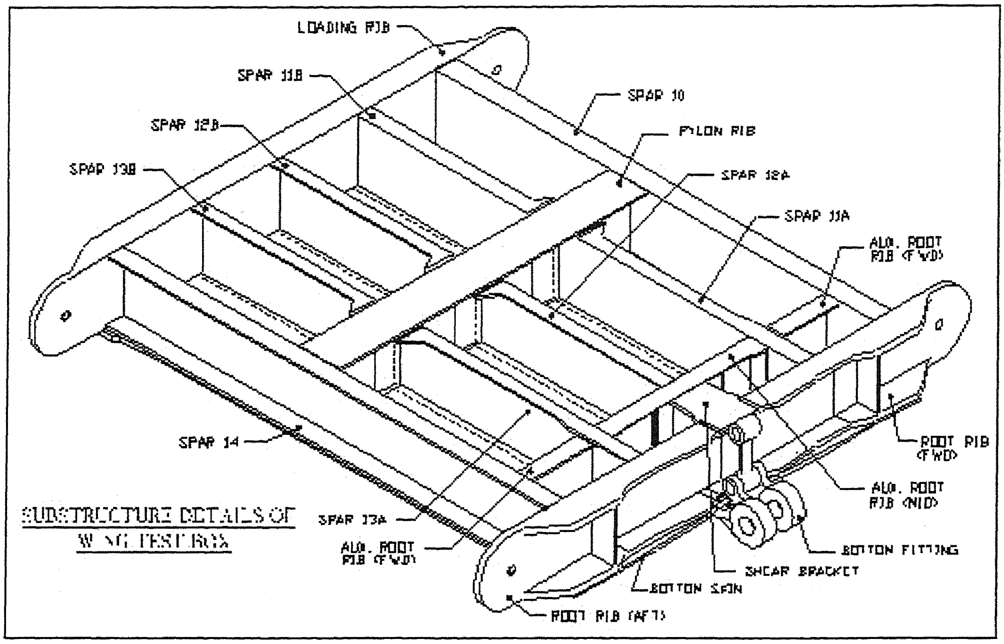


Figure 1. Wing test box assembly (top skin has been removed to show internal details)

Figure 2. A photograph of the co-cured substructure.

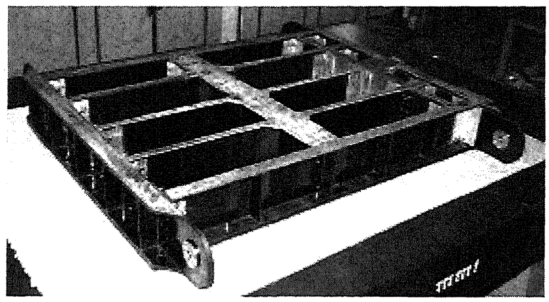


Figure 3. A view of the partial assembly of the wing test box.

2. ROOM TEMPERATURE TESTING OF THE WING TEST BOX

The test box representing a portion of the wing is expected to withstand mainly the forces of: bending moment (M), torsional moment (T), and shear forces (S). The design ultimate loads are equal to 1.5 times the limit load which corresponds to the maximum upbending moment manoeuvering load case.

In view of the single fitting option chosen for the present design, the root fitting can be expected to withstand only the bending moment and the shear force while the box takes all the three loads. The magnitudes of the loads P1, P2, P3, P4 and P5 are 23000, 23000, 12000, 70000, and 58000 (in Newtons) respectively. P1 and P2 are applied at the ends of the root rib. P1 is applied at the end near Spar 10 (root rib fwd) in the positive (up) direction and P2 at the end near Spar 14 (root rib aft) in the negative (down) direction. P3 is applied on the loading rib at the end near Spar 10 and P4 is applied on a loading bracket fixed to the loading rib below Spar 12B. P5 is applied on the loading rib near spar 14. P3, P4 and P5 are applied in the positive (up) direction. The loading points for P1, P2, P3 and P5 are visible in Fig. 1.

The test box was mounted on a test rig by means of a special root fitting attachment fixture that connects the root fitting to the test rig. The static loads were applied at the loading points by means of hydraulic jacks. Multi-axis hydraulic jacks with power packs and controllers were used. Load cells were used in conjunction with the jacks to monitor the loads.

Dial gauges and strain gauges were used to monitor the deflections and the strains, respectively. The dial gauges were placed at each of the loading points, and also at the intersection points of the spars with the loading and pylon ribs. The test box was extensively in instrumented with the strain gauges. The loads were applied in steps of 10% of the limit load, and the corresponding strains and deflections measured. Fig. 4 shows the test box mounted on the test rig with the loading rib jacks visible in the picture. In order to simulate the fuel pressure in the wing test box, arrangements were made to seal the box and apply a pressure of 7 psi. The aim was to apply the static load and the internal pressure simultaneously.

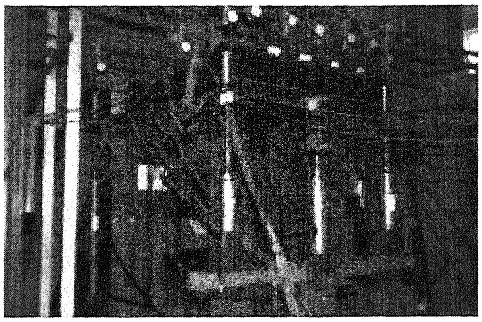
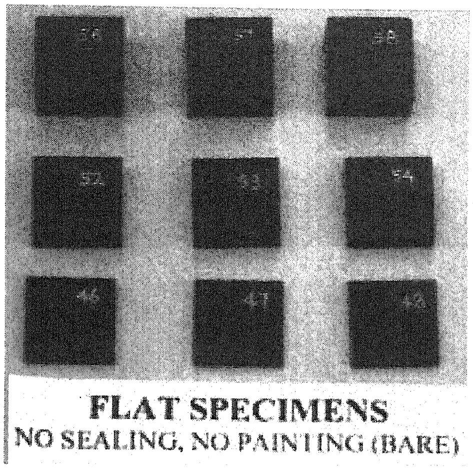


Figure 4. The cocured wing test box being statically tested under room temperature conditions.

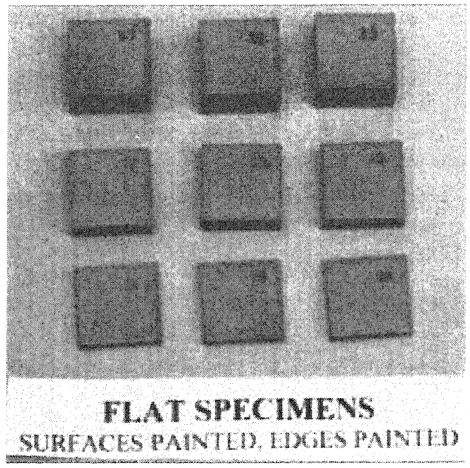
3. ENVIRONMENTAL CONDITIONING

In order to condition the box, it was placed in an environmental chamber that was maintained at 95% RH and 70 deg C. The normal procedure for specimen level and feature level environmental conditioning is that they are removed periodically and weighed, and the moisture content is determined from the weight increase from the dry specimen. However, this procedure is not practical for a box so large and heavy. Nevertheless, it is important to ensure that the box is completely saturated with moisture in the as-assembled condition because it is exposed to the ambient conditions in the field in this assembled condition. Usually, specimen conditioning is done in the as-fabricated condition. But, in the actual case, paints or sealants are usually applied on airframe components. Moreover, typically an airframe component is of varying thickness in different regions, as in the case of the test box. Thus, these factors should be taken into account while conditioning. In order to study the effects of the above mentioned factors, different specimens and features were placed in the environmental chamber along with the test box.

The specimens and features fabricated were flat specimens, T-joints and boxes. The flat specimens were 25mm x 25 mm in size with varying thickness of 3.6 mm, 9 mm and 15.9 mm. Among the flat specimens, for each thickness, four sets were fabricated: (i) one set was sealed at the edges to prevent moisture absorption through the edges and the faces were bare, (ii) one set was painted on the faces and sealed on the edges, (iii) one set was painted on the faces and the edges, and (iv) one set was totally bare, i.e., it was neither painted nor sealed. The paint used here was the standard epoxy yellow primer used in the aircraft industry. The sealing was done using the PR sealant 1422. The bare specimens and the painted specimens are shown in Figs 5(a) and 5(b), respectively. T-joints were also fabricated and conditioned along with the test box. The schematic and the photographs are shown in Figs. 6(a) and 6(b) respectively. In addition to the flat laminates and T-joints, two sets of boxes were also fabricated and placed in the chamber. These were of the size 50mm x 50mm x 56mm and of thickness 9mm. One set was completely closed (Fig. 7(a)). This was to study if the complete sealing of the box results in lower levels of moisture absorption. Another set had two holes of 10mm dia on two faces to allow for moisture to be absorbed from the inside of the box (Fig. 7(b)). Each of these specimens and features were periodically removed (once a week) and weighed and the moisture content noted. This was done until saturation in the moisture levels of all the features and specimens were observed, which took approximately 14 months. The comparisons of the moisture absorption rates for the flat specimens of thickness 9mm and 15.9mm with different treatments are shown in Figs 8 and 9, respectively. It can be seen that the treatments do not substantially affect the rates. The effect of thickness of the specimens is shown for the bare specimens in Fig. 10. The thinner specimens absorb moisture at a faster rate than the thicker specimens although the saturation levels are the same. The moisture absorption rates for the box specimens and the T-joints are plotted in Fig 11. The T-joints absorb moisture at a faster rate and also saturate at a higher level. The open box also absorbs moisture faster and saturates a level marginally higher than the closed box.

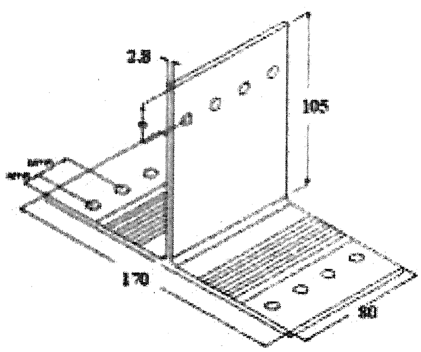


(a)

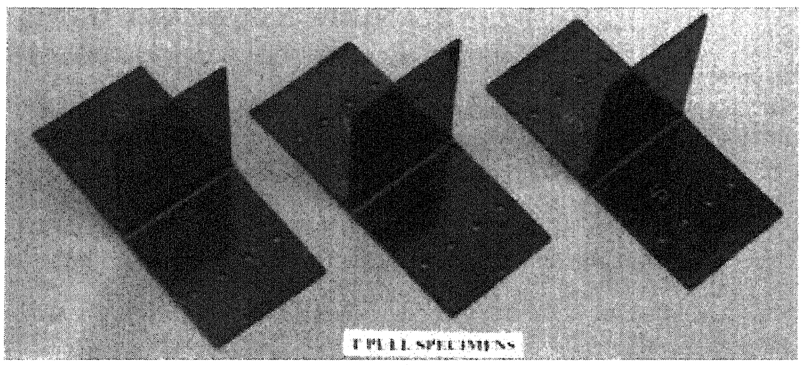


(b)

Figure 5. Flat specimens that were saturated along with the box. (a) bare specimens, (b) painted specimens. Each row is a specimen of varying thickness (from top to bottom, 3.6 mm, 9 mm and 15.9 mm).

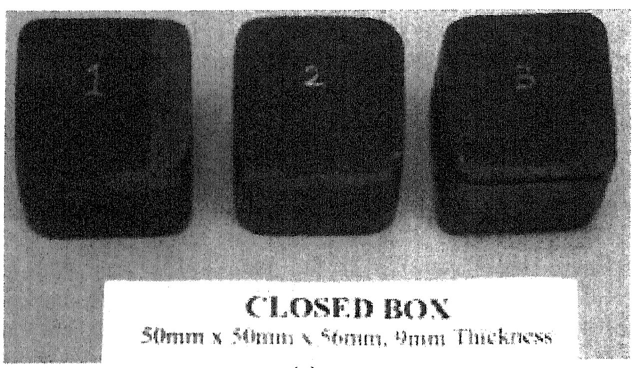


(a)

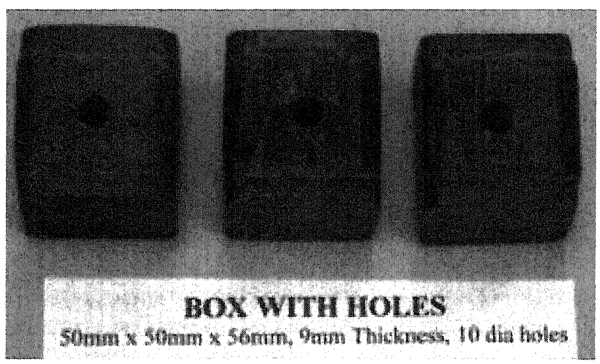


(b)

Figure 6. (a) Schematic of T-joint that was saturated with the box (dimensions in mm). The base skin thickness is 3.6 mm, (b) Photographs of the T-joints.



(a)



(b)

Figure 7. Box specimens saturated along with the box. (a) completely closed box, (b) box with 10 mm dia holes on two faces to allow for moisture absorption through inside surfaces.

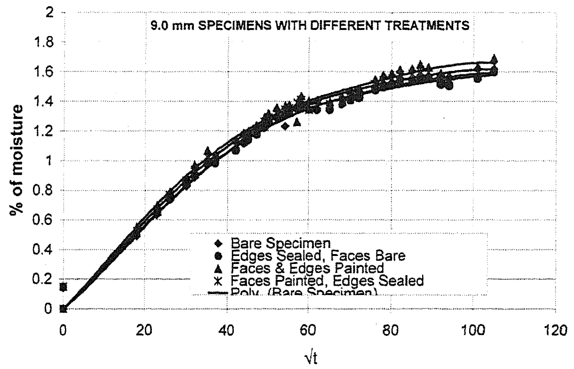


Figure 8. Moisture absorption rates for 9mm specimens with different treatments.

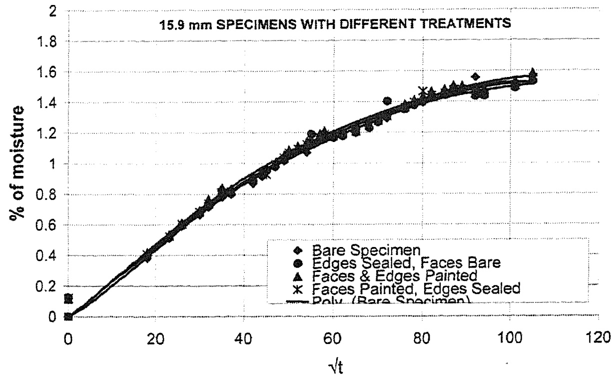


Figure 9. Moisture absorption rates for 15.9mm specimens with different treatments.

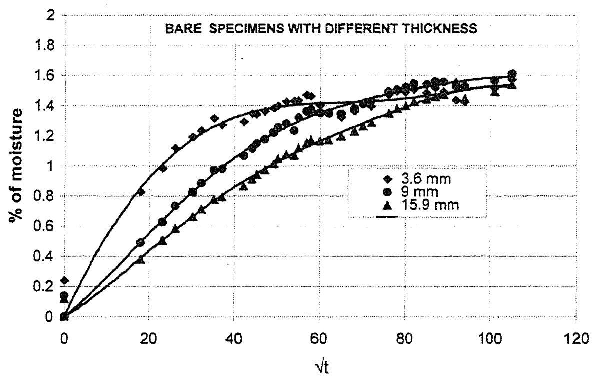


Figure 10. Moisture absorption rates for bare specimens

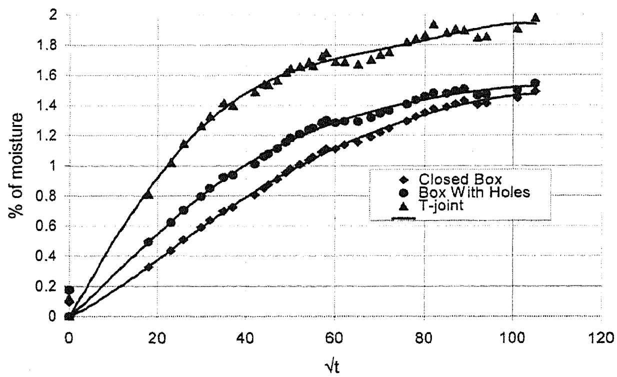


Figure 11. Moisture absorption rates for box and joints

4. ENVIRONMENTAL TESTING

Based on the moisture levels of the specimens and features, it was inferred that the test box was saturated. The test box was then statically tested while maintaining the temperature and humidity conditions. The temperature and humidity conditions were made by the use of steam. In order to maintain the steam around the test box, a flexible bag was made around the box and sealed with a silicone base rubber sealant (Fig. 12). In order to prevent loss of heat and condensation of steam, a GI sheet box slightly bigger than the test box was made in two halves. A thermocol padding of 25 mm was placed as a lining on the inside of the GI box. An additional layer of asbestos was placed on the inside. Four steam inlet holes were made in the bottom of the box and one outlet was made to enable the draining of condensed steam. These holes were also made through the flexible bag envelope. Near the loading points, root fitting area and the dial gauge locations, the flexible bag was sealed to the test box to provide access to jacks and dial gauges (Fig. 12). Finally, the top of the GI box was placed over the bottom half and connected to it. The setup is shown in Fig. 13.

The steam was generated using four steam generators of around 20 litre capacity each and size of 240 x 280 x 330 mm. The salient features of these in-house fabricated steam generators were (i) float valve based water overflow control, (ii) safety vent to open if the pressure exceeds about 0.8 bar, (iii) closed loop temperature control, and (iv) 230V AC, 2 kW heater. Heat insulation was provided on all the sides of the heater. Some thermocouples were bonded to top surface using repair paste and were covered with a piece of thermocol to prevent direct heating from steam. A small vacuum bag was placed over the sensor to avoid condensed water accumulating. Note that the stream inlets were placed at the bottom of the box. Some thermocouples were also kept at about 15mm from the surface to measure the ambient temperature within the bag. The thermocouple measurements were acquired and recorded using a laptop PC. The RH inside the bag was measured by inserting an electronic humidity sensor in to the bag through the steam outlet. The measurements showed that the temperature and humidity were maintained to the required levels through out the test.

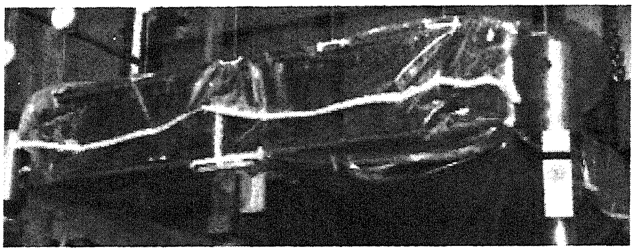


Figure 12. Flexible bagging around the box for the steam.

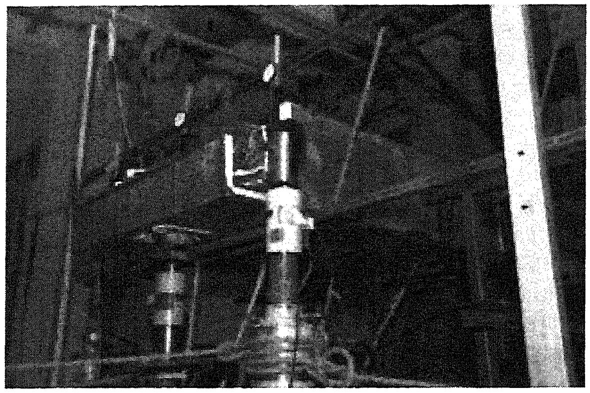


Fig. 13. Wing test box enclosed in the bag and the insulating outer box.

5. ROOM TEMPERATURE AND HOT-WET TEST RESULTS

As mentioned earlier, the room temperature tests were carried out in which the design ultimate load was applied on the test box. No failure was observed during the test. Subsequent NDE inspection of the skins and the cocured joints also showed that there was no failure. The strains and deflections showed a linear trend until the ultimate load. The ultimate load test was also conducted with an internal pressure of 7 psi to simulate fuel pressure. Suitable sealing procedures were adopted in order to maintain the pressure. The pressurized test was done to see if the strength of the joints is reduced due to a peeling stress caused by the internal pressure. However, no failure was observed until ultimate load. Moreover, there was also no perceptible change in the stiffness of the structure due to this pressure. The deflections at the loading end of the test box are plotted in Figs. 14 and 15. The strains in the top and bottom skin are plotted in Figs. 16 and 17, respectively.

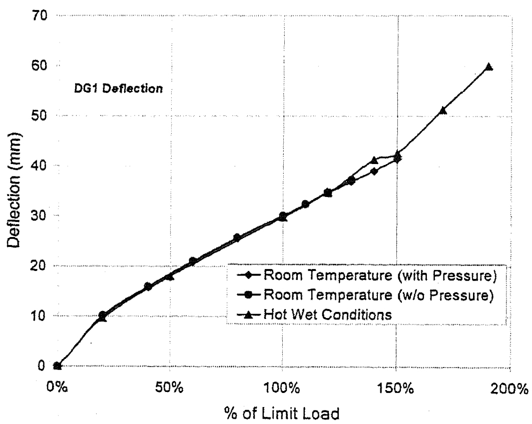


Figure 14. Comparison of deflection at end of loading rib

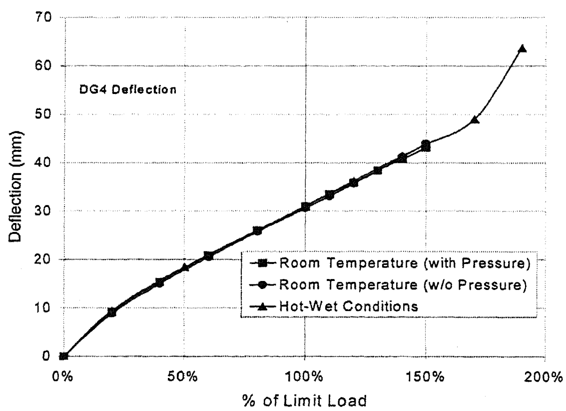


Figure 15. Comparison of deflection at mid of loading rib

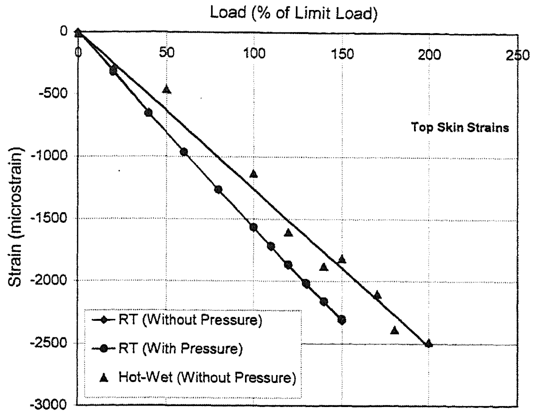


Figure 14. Comparison of strain on the top skin.

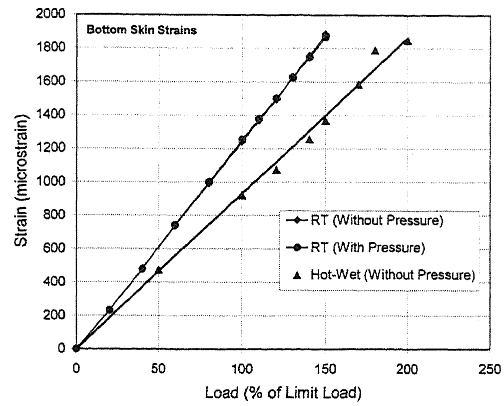


Figure 15. Comparison of strain on the bottom skin.

Subsequent to room temperature testing, the strain gauges were removed. After saturation, strain gauges were again mounted at specific locations for comparison purposes. Similarly, the deflections were also monitored at same locations. The hot-wet testing was done until 200% of the limit load. The comparisons of the deflections are plotted in Figs 14 and 15. It can be seen that there is no observable difference in the deflections or the slopes between room temperature and hot-wet conditions. The change in slope in the load-deflection curve after ultimate load (150% limit load) is attributed to the yielding of the metallic root fitting. The strain comparisons are shown in Figs 16 and 17. Since the deflections did not show any change in the slope, the small change in the slopes could be attributed to minor variations in the reaffixing of the strain gauges and small drifts in strains due to the temperature and humidity conditions.

6. SUMMARY AND CONCLUSIONS

A cocured composite testbox was designed, fabricated and tested. The objective of this study is to closely examine the feasibility of fabricated a large and complex structure such as a main root box of an aircraft using cocuring technology. The results of the static testing done under room temperature and hot-wet conditions are presented here. In order to conduct the hot-wet tests for such a large structure, a rational and systematic approach was conceived and applied. Specimens and features were placed along with the box in the environmental chamber for conditioning. Different treatments such as sealant and paint were applied on the specimens to study the effect of these in the moisture absorption rates. It was found that the treatments had no substantial effect on the rate or percentage of moisture absorption. To examine the effect of having a box construction on the moisture absorption, closed and open boxes were fabricated and conditioned with the test box. T-joints were also conditioned with the test box. These specimens and features were periodically inspected for the moisture content and upon their saturation the test box was tested. A special chamber using a combination of flexible bagging and insulating box structure was fabricated around the test box. Steam generators were fabricated and used to generate the steam that maintains both the humidity and temperature.

The results of the hot-wet testing have shown that there is no appreciable change in the stiffness of the test box. Under these conditions, the test box was tested up to 200% of the limit load. The box was then inspected using ultrasonic scanning and it was found that the cocured joint areas in the substructure were intact. This study thus clearly demonstrates the feasibility of fabricated a wing test box using the cocuring technique.

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